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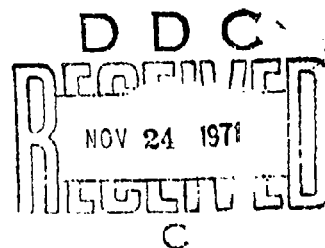
ALKALINE CADMIUM ANODE STUDIES

Otto C. Wagner
Robert L. Smith

August 1971

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ALKALINE CADMIUM ANODE STUDIES

Otto C. Wagner
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Power Sources Technical Area
Electronics Technology and Devices Laboratory

AUGUST 1971

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ABSTRACT

Sponge cadmium anodes without any additives, except for the 5% carbon-yl nickel powder conductor, showed the best performance characteristics in terms of: (a) not poisoning the nickel-hydroxide cathodes, (b) having very high weight and volume energy densities, (c) exhibiting excellent active material utilizations over a temperature range of -40°F to 125°F , and (d) showing the best capacity maintenance during prolonged deep cycling (100% depth of discharge). A ferric oxide extender is very beneficial to cadmium in terms of preventing "fade-out"; i.e., loss of electrical capacity by the growth of cadmium and cadmium hydroxide crystals. However, after 5 cycles, ferric oxide produces a significant loss in capacity on the nickel-hydroxide positive. In the presence of ferric oxide, the oxygen overpotential of the nickel hydroxide is reduced by about 50 to 80 mV, a process that reduces the charge acceptance of the positive. On prolonged cycling, the capacity loss of the cathode becomes progressively worse and after 250 deep cycles the cell becomes virtually non-functional. In cadmium-air cells, the ferric oxide exhibits no adverse effect on the platinum catalyzed air cathodes. For the present time, therefore, the sponge cadmium anode best suited for high energy density nickel-cadmium batteries appears to be the one without any extender or expander. However, for cadmium-air batteries, and possibly for silver-cadmium batteries, the sponge anode containing 5% Fe_2O_3 is optimally suited. Other additives, such as indium and titanium dioxide, produced no significant improvements in anode performance. Additives compatible with the nickel-hydroxide cathode will be screened for the purpose of preventing "fade-out" and "memory" type capacity losses.

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<p>Sponge cadmium anodes without any additives, except for the 5% carbonyl nickel powder conductor, showed the best performance characteristics in terms of: (a) not poisoning the nickel-hydroxide cathodes; (b) having very high weight and volume energy densities, (c) exhibiting excellent active material utilizations over a temperature range of -40°F to 125°F, and (d) showing the best capacity maintenance during prolonged deep cycling (100% depth of discharge). A ferric oxide extender is very beneficial to cadmium in terms of preventing "fade-out"; i.e., loss of electrical capacity by the growth of cadmium and cadmium hydroxide crystals. However, after 5 cycles, ferric oxide produces a significant loss in capacity on the nickel-hydroxide positive. In the presence of ferric oxide, the oxygen overpotential of the nickel hydroxide is reduced by about 50 to 80 mV, a process that reduces the charge acceptance of the positive. On prolonged cycling, the capacity loss of the cathode becomes progressively worse and after 250 deep cycles the cell becomes virtually non-functional. In cadmium-air cells, the ferric oxide exhibits no adverse effect on the platinum catalyzed air cathodes. For the present time, therefore, the sponge cadmium anode best suited for high energy density nickel-cadmium batteries appears to be the one without any extender or expander. However, for cadmium-air batteries, and possibly for silver-cadmium batteries, the sponge anode containing 5% Fe₂O₃ is optimally suited. Other additives, such as indium and titanium dioxide, produced no significant improvements in anode performance. Additives compatible with the nickel-hydroxide cathode will be screened for the purpose of preventing "fade-out" and "memory" type capacity losses.</p>			

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ALKALINE CADMIUM ANODE STUDIES

INTRODUCTION

In the USAECOM internal program on the development of the cadmium-air battery, the loss in capacity by the cadmium anode was overcome by mixing 5% Fe_2O_3 and 5% carbonyl nickel powder into the active CdO powder.^{1,2,3} Fleischer⁴ reports that 1% indium expander* favorably improves the solid state reaction of the cadmium anode. This expander is reported to significantly improve the low temperature performance of the cadmium anode. However, it is also reported that the beneficial effects of indium do not become apparent until after 50 to 100 cycles. Finally, in addition to the need for extenders** and expanders, the state-of-the-art alkaline cadmium anode requires a conductor. This is provided by mixing 5% carbonyl nickel powder or finely divided silver powder into the active CdO . For high rate application (greater than the C rate), the USAECOM cadmium anode was rendered highly conductive by pasting the active CdO mix into a foam nickel matrix of 97% \pm 1% porosity and then compressing the electrode to a porosity of 60-65% (in the charged state).¹

EXPERIMENTAL PROCEDURE

The sponge cadmium anodes were prepared in the following manner: (a) cadmium oxide (Fisher Certified, Cat. No. C-16) was homogeneously blended with 5% by weight of carbonyl nickel powder (International Nickel Company, Type 255) and 2.5-5% by weight of extender, if so desired. (The ferric oxide extender (Fisher Certified, Cat. No. I-116) and the Teflon extender (Dupont TFE 40) were employed in this study. Titanium dioxide (Fisher Certified, Cat. No. T-315) was also investigated as an extender. Indium hydroxide was investigated as an expander (to render $\text{Cd}(\text{OH})_2$ more p as a semiconductor)), (b) 3.50 grams of cadmium oxide mix were mold pressed into an electrode containing an Aldex paper wrap (Aldine Corporation), a 5 Ni-15-2/0 nickel Emnet grid (Emnet Corporation), and a nickel tab. The electrode dimensions were: 0.026" in thickness, 1-1/2" in height, and 1-7/8" in width; the electrode porosity (in the fully charged state) was 62.5%. The unit nickel-cadmium cells were constructed as follows: (a) one test cadmium oxide anode was inserted into a heat sealed polyamide Pellon bag of 6 mil thickness (2506K, Pellon Corporation), (b) two nickel hydroxide cathodes - the capacity of the two cathodes being much greater than the single cadmium anode - were also inserted into heat-sealed polyamide Pellon bags, and (c) a partially charged nickel hydroxide electrode was also wrapped by 6 mil polyamide Pellon (this electrode serves as a reference electrode).

*An expander is a material that incorporates itself in the crystal lattice of the active host material.

**An extender is a material that blends with the particles of active material and thereby blocks the growth of smooth, pure crystals.

In the case where the single electrode cell contained a single test nickel hydroxide cathode and two sponge cadmium anodes, the test cell was designed to determine the effect of the cadmium anode on the performance characteristics of the nickel cathode. The electrode pack was finally inserted into a small cycloc cell case and shimmed so that the internal cell pack pressure fell in a range of 1-5 psig. The cell construction was completed by attachment of cell cover and terminals. After cell assembly, and allowing sufficient time for the Epoxy cement to dry and set, the cell was filled with 30% KOH +1% LiOH to a level one half the height of the electrodes.

The cell was cycled using an automatic cycler with the voltage cutoff set at 1.55-1.75 volts on charge (depending on rate) and 0.80 volts on discharge. Cell and reference readings were taken with a potentiometer. Charge-discharge curves were automatically recorded by a Honeywell-Electronik voltage recorder. Since the cells had Bunsen valves attached to each vent, carbonation of the electrodes was slight.

RESULTS AND DISCUSSION

Performance of Single Sponge Cadmium Anodes in Nickel-Cadmium Cells at Various Rates and Temperatures

As was pointed out in earlier USAECOM studies of the cadmium anode,^{1,2,3} an electrode had been developed to deliver 0.30 Ah per gram of electrode weight at the C/5 rate. These electrodes were of the sponge type and maintained about 80% of theoretical capacity when continuously cycled at 100% depth of discharge (C/5 rates of charge and discharge).¹ Loss of capacity was prevented by: (a) employment of 5% Fe₂O₃ extender, (b) elimination of carbonate within the cell, (c) moderate overcharging during initial cycling, and (d) charging at rates between C/5 and C/2. Shorting by cadmium penetration through the separator system was prevented by: (a) elimination of carbonate, and (b) the employment of bibulous inert interseparators between the anode and main separator.

In this second phase of the program, to improve the electrochemical performance of the alkaline cadmium anode, effort was directed towards: (a) testing three optimally designed anodes in single electrode cells (one test negative and two positives with excess capacity) at various discharge-charge rates and at various temperatures, (b) determining the compatibility of the anodes with state-of-the-art nickel hydroxide electrodes, and (c) ascertaining the cycle life of the anodes in positive limiting nickel cadmium cells (which is the standard design feature of secondary batteries).

Table I shows the performance data of various cadmium anodes from cells that were designed negative limiting; i.e., one anode and two nickel

hydroxide cathodes with excess capacity. In the main, the following types of negatives were studied:

<u>Cell</u>	<u>Negative</u>
NC-69-1	Sponge: 95 CdO + 5 Ni (control)
NC-69-2	Sponge: 90 CdO + 5 Ni + 5 Fe ₂ O ₃
NC-69-3	Sponge: 94 CdO + 5 Ni + 1 In
NC-69-4	Sponge: 89 CdO + 5 Ni + 1 In + 5 Fe ₂ O ₃
NC-69-5	Sintered Nickel Cd Anode from Sonotone
NC-70-1	Sponge: 95 CdO + 5 Ni (repeat of control)
NC-70-2A	Sponge: 90 CdO + 5 Ni + 5 Fe ₂ O ₃ (repeat)
NC-70-3	Sponge: 92.5 CdO + 5 Ni + 2.5 TiO ₂
NC-70-2B	Sponge: 90 CdO + 5 Ni + 5 Fe ₂ O ₃ (repeat)

The test cells were regimed at various rates of charge and discharge and at various temperatures; namely, 36 mA/in² (1000 mA), 90 mA/in², and 180 mA/in²; -40°F, -25°F, 80°F, and 125°F, respectively. From the data in Table I, the following is apparent:

a. The anode with 5% ferric oxide extender exhibited the highest energy density on both a weight and volume basis, particularly at low temperatures and high rates of charge and discharge.

b. The standard sintered-nickel cadmium anode possesses the lowest energy density and specific capacity of all the electrodes tested. As a matter of fact, the sponge anode (NC-69-1, NC-70-1) without any extender or expander has an energy density almost double that of the standard electrode.

c. Fe₂O₃ lowers the hydrogen overpotential of the cadmium anode by 50-150 mV, depending on the rate of charge.

d. Indium expander showed no significant improvement in anode performance. However, it is reported that the beneficial effects of this additive do not become manifest until after 50 to 100 cycles.

e. Titanium dioxide extender, likewise, did not show any significant improvements in cell performance.

The pertinent findings of this investigation are shown in graphic form in Figures 1 to 4. Figure 1 shows the cadmium utilization at various temperatures in terms of ampere-hours per gram of cadmium metal of a sponge

anode without extender (control, open circles), a sponge electrode with 5% Fe_2O_3 extender (black circles), and a sintered-nickel cadmium anode (open squares). The discharge rate was 200 mA (36 mA/in^2). Figure 2 shows the utilization of the same electrodes at the 1.00 ampere rate (180 mA/in^2). Figure 3 is a plot of ampere-hours per weight of cadmium plate at various temperatures, the rate being 200 mA. This figure clearly points out the vast superiority of the sponge anodes over the standard sintered types. Finally, Figure 4 shows the specific capacity (Ah/in^3) of the three electrodes at various temperatures. Again, the contrast between the sponge and sintered electrode is vividly manifested.

Performance of Single Nickel Hydroxide Cathodes as Affected by the Sponge Cadmium Anodes

Although the single anode cell tests of the preceding section showed the sponge anodes, particularly the one with 5% Fe_2O_3 extender, to be the good electrodes, their compatibility with the nickel hydroxide positive must still be determined, especially over a period of prolonged deep discharge cycling.

Table II shows the performance data of three single electrode cells at various temperatures and rates of charge and discharge. The cells were designed with one nickel hydroxide cathode and two sponge cadmium anodes with excess capacity. The cell constructions were as follows:

<u>Cell</u>	<u>Type Positive</u>	<u>Type Negative</u>
NC-70-4	1 X Texas Instruments	2 X Sponge 95 CdO + 5 Ni
NC-70-5	1 X Texas Instruments	2 X Sponge 90 CdO + 5 Ni + 5 Fe_2O_3
NC-70-6	1 X General Electric (SAFT)	2 X Sponge 95 CdO + 5 Ni

From the table, the following is apparent:

a. Fe_2O_3 is detrimental to the nickel hydroxide positive. This becomes significant after 4 to 5 deep discharge cycles. In the presence of Fe_2O_3 , the oxygen overpotential of the positive is reduced to about 40-80 mV, which probably accounts for the mechanism of the capacity loss.

b. The sponge negative without any additives is very compatible with the nickel hydroxide cathode.

Cycling Data of Single Nickel Hydroxide Cathodes Coupled with Various Sponge Cadmium Anodes

The three cells of the preceding section were placed on an automatic cycler to be cycled for life. Charging was at 500 mA for two hours at room temperature. Discharging was at 500 mA to a voltage cutoff of 0.30 V.

The capacity maintenance curves of the three cells are shown in Figure 5. Here it is seen that Fe_2O_3 will rapidly degrade the cell capacity to a non-functional level in less than 250 cycles. Fortunately, the cells with the sponge anodes containing no additives (except for 5% carbonyl nickel conductor) did not impair the electrochemistry of the nickel hydroxide cathode over the 300 cycles tested.

On the basis of these findings, the only acceptable anode for a state-of-the-art nickel-cadmium battery is the sponge anode without additives. However, as shown in Figures 1 - 4, the incorporation of a beneficial extender is desired, particularly at low temperatures and high rates of discharge; therefore, the search for a compatible extender and/or expander is fully warranted.

CONCLUSIONS

At the present time, the best cadmium anode in terms of maximum utilization of active materials and maximum weight and volume energy densities in nickel-cadmium cells is a sponge cadmium electrode with 5% nickel carbonyl conductor. In addition, this electrode exhibited the best maintenance of electrical capacity during prolonged deep discharge cycling. In addition, its capacity was excellent over a temperature range of -40°F to 125°F .

Ferric oxide which is a very beneficial cadmium extender in cadmium-air cells and in negative limiting nickel-cadmium cells, was detrimental to the nickel hydroxide cathodes in nickel-cadmium cells after 5 cycles.

Other additives, such as an indium expander and a TiO_2 extender, were found to have little affect on the capacity of the cadmium anode.

FUTURE WORK

Extenders will be investigated which are compatible with the nickel-cadmium system. Materials must be selected that: (a) do not lower the oxygen overpotential of the nickel hydroxide electrode, (b) possess crystal lattice parameters similar to that of $\text{Cd}(\text{OH})_2$, (c) are relatively insoluble in alkali, (d) do not lower the hydrogen overpotential of the cadmium anode appreciably, and (e) do not increase the resistivity of the anode.

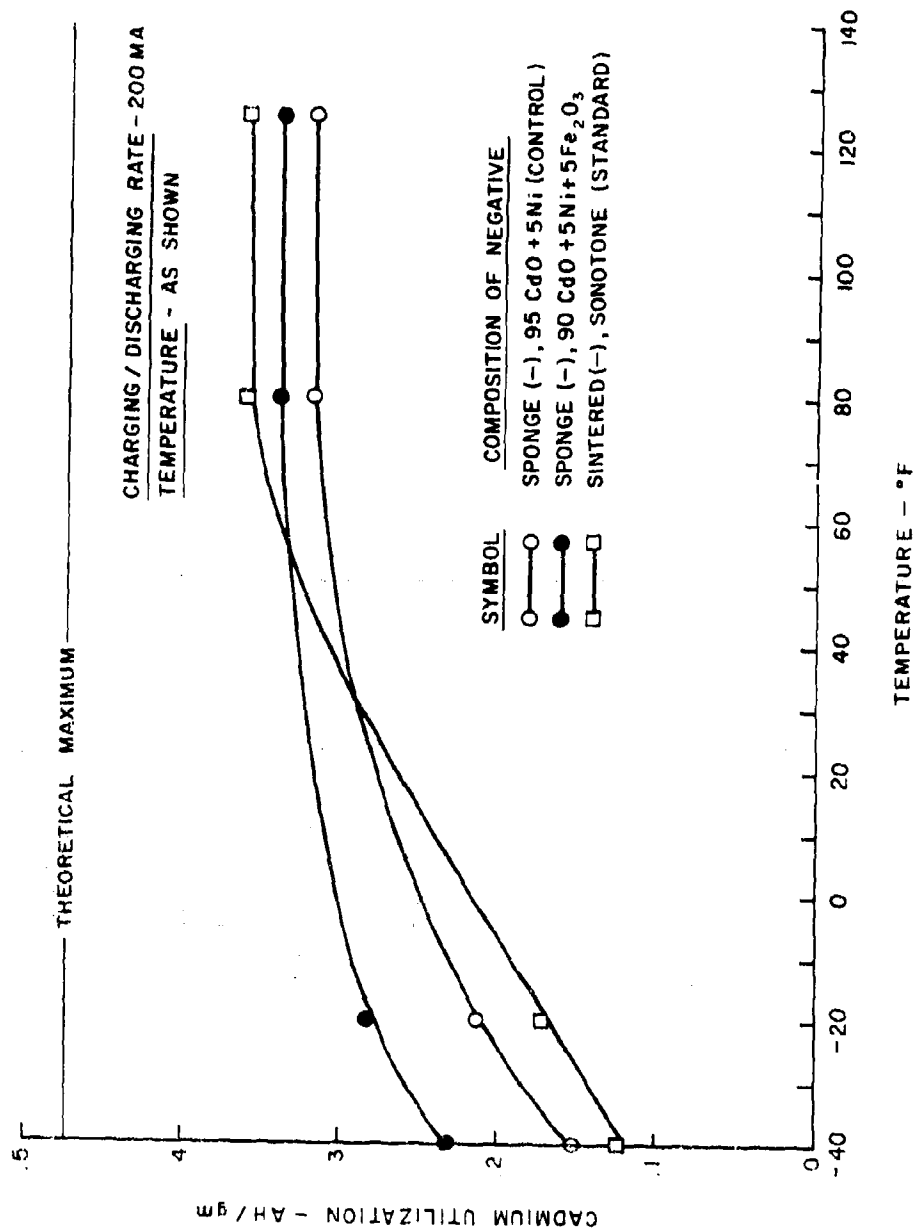
Negatives with indium expanders and TiO_2 extenders should be life cycled versus a control to determine if "memory" or "fade-out" can be prevented.

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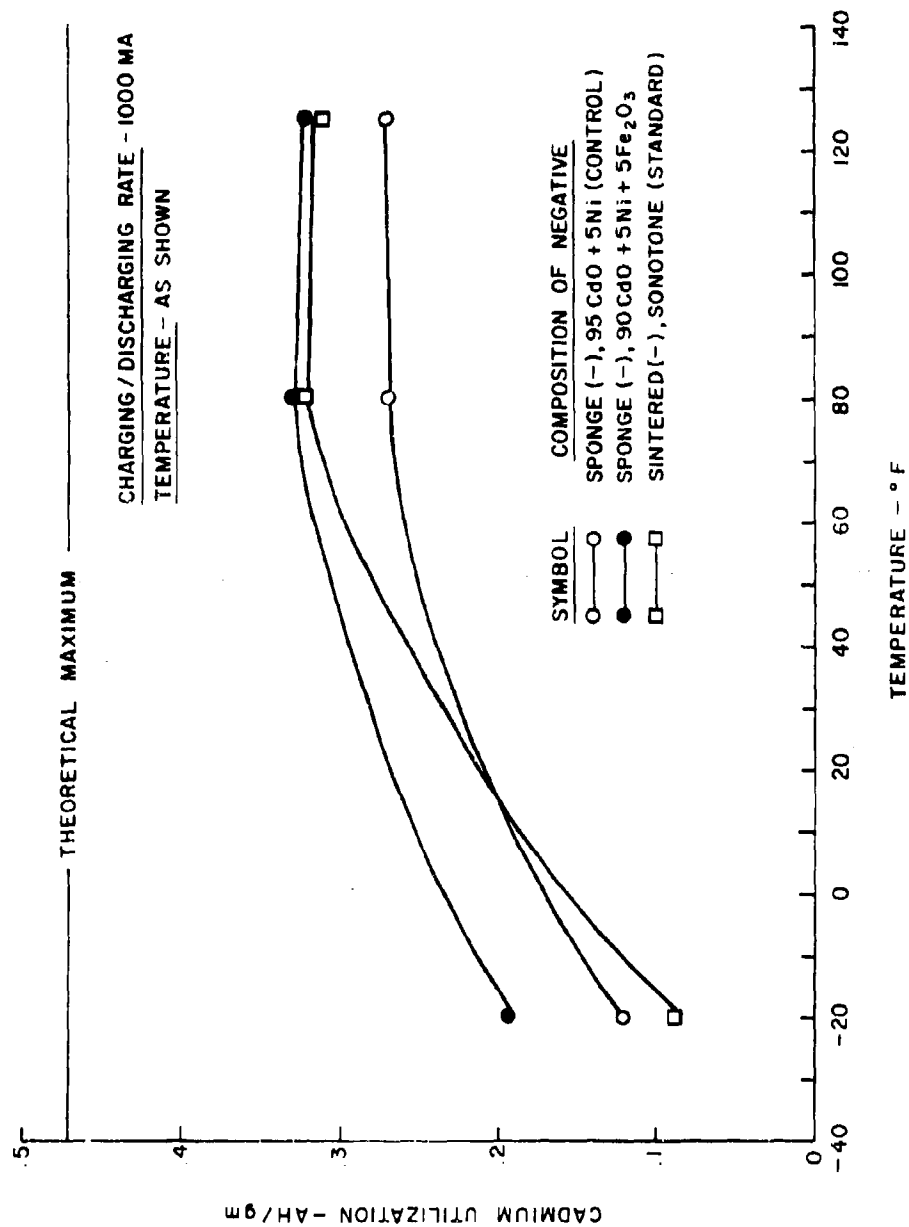
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2. O. C. Wagner, "Secondary Cadmium-Air Cells," Proc. 22nd Annual Power Sources Conference, May 1968.

3. O. C. Wagner, "Secondary Cadmium-Air Cells," Journal of the Electrochemical Society, Vol. 116, No. 5, May 1969.

4. A. Fleischner, U.S. Patent No. 2,771,499 (November 20, 1956).



CADMIUM UTILIZATION OF VARIOUS CADMIUM ANODES AT VARIOUS
TEMPERATURES - C.D. : 36 MA / IN²
FIG. 1



CADMIUM UTILIZATION OF VARIOUS CADMIUM ANODES AT VARIOUS
TEMPERATURES - C.D. : 180 MA/IN²

FIG. 2

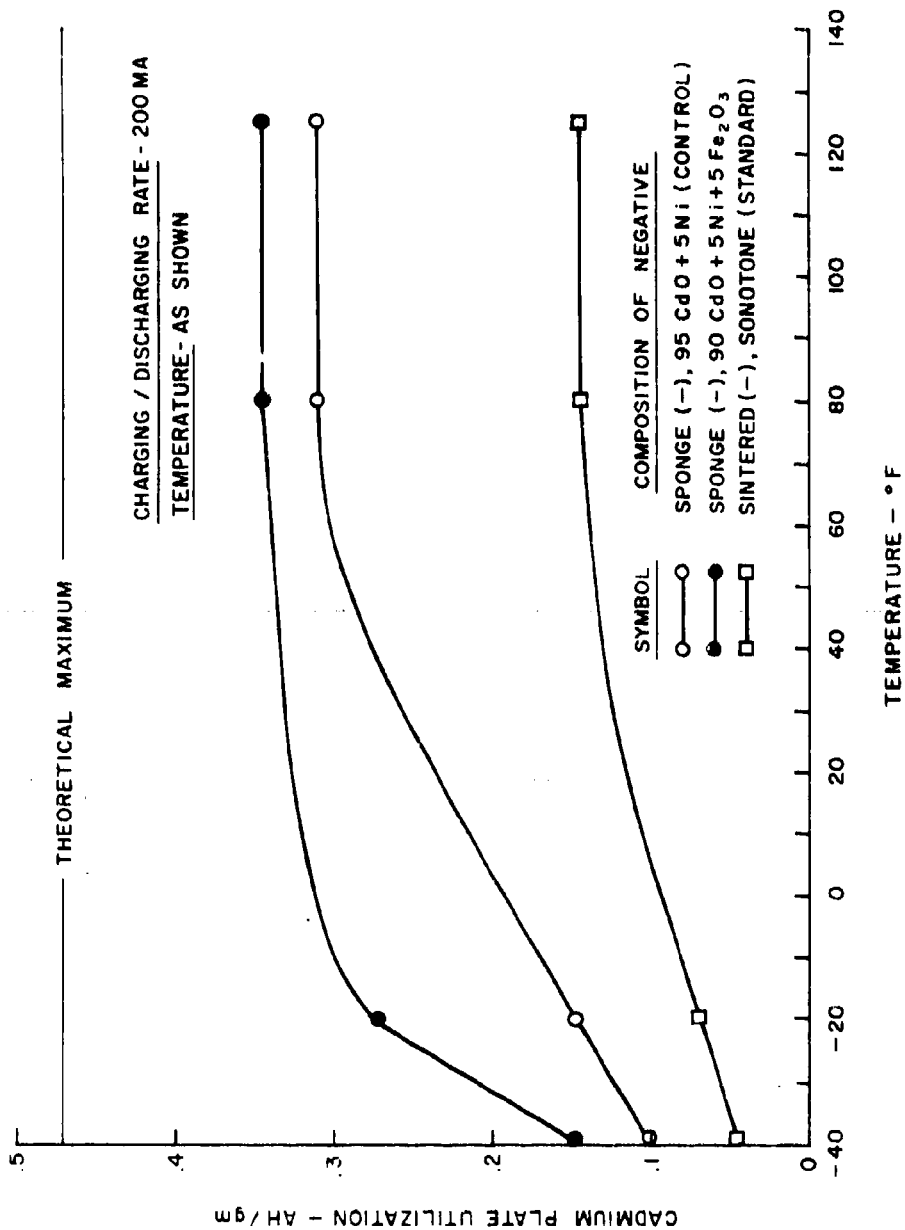


PLATE UTILIZATION OF VARIOUS CADMIUM ANODES AT VARIOUS
TEMPERATURES - C.D. : 36 MA/IN²

FIG. 3

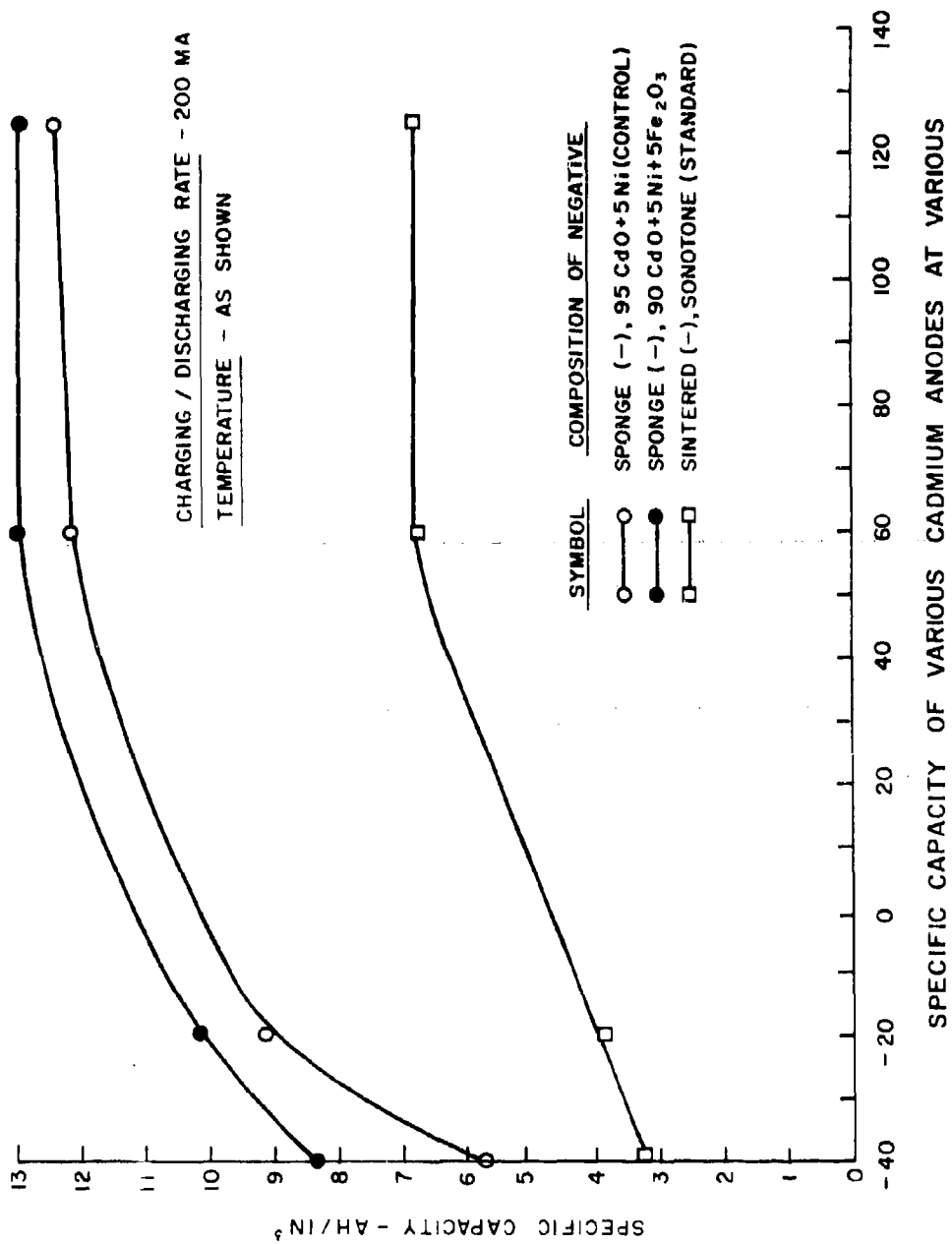
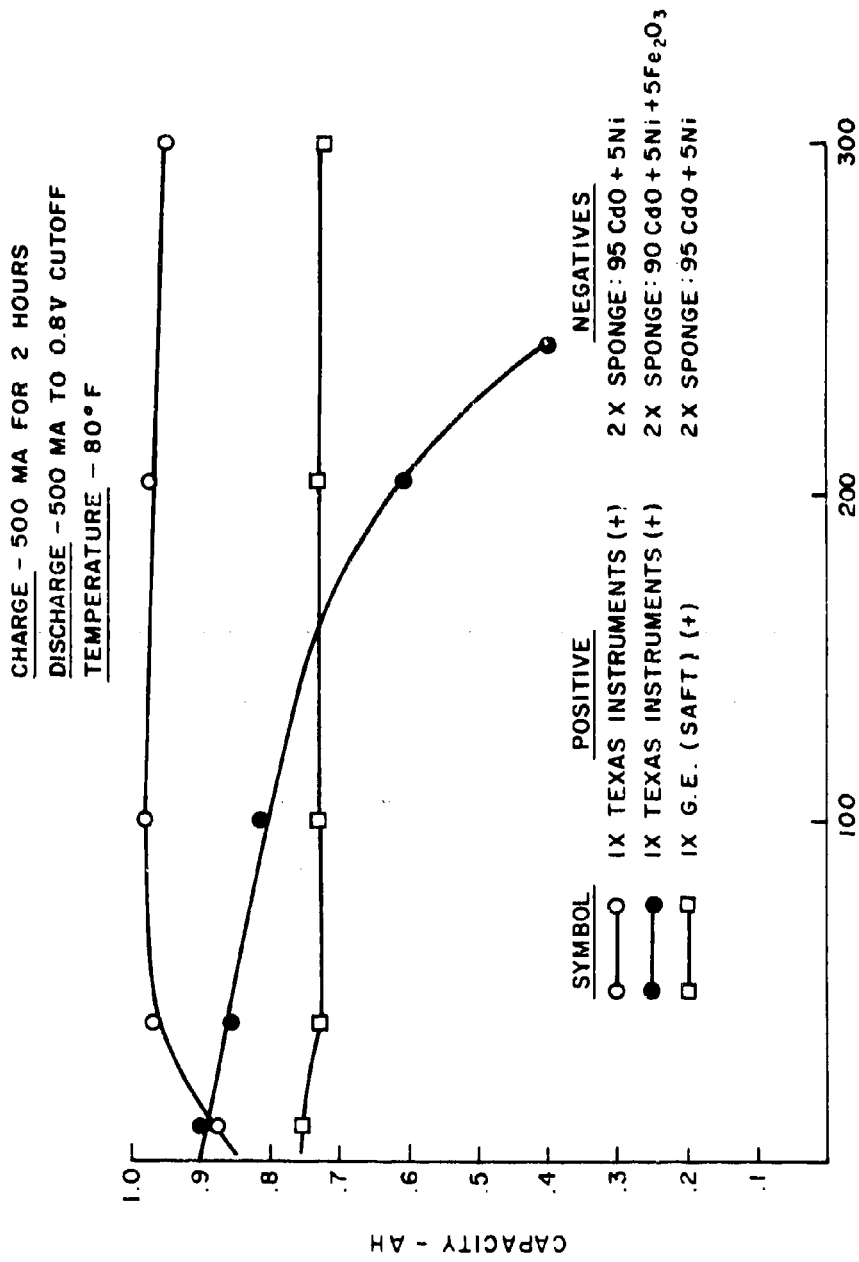


FIG 4



CAPACITY MAINTENANCE OF VARIOUS NICKEL - CADMIUM CELLS

FIG. 5

Table I. Performance Data of Various Cadmium Anodes

Cell No.	Cycle No.	Rate-Charge and Discharge		Capacity (Ah)	Ah per inch cubed	Plate Weight Per Ah		Utilization of Cadmium (g/Ah)	% of Theoretical Capacity	Temp. °F	Final Potential (-) on Charge *	
		(mA)	(g/Ah)			(g/Ah)	(g/Ah)				(V)	(V)
NC-69-1	3	200	0.89	12.2	4.64	3.16	67	80	1.40			
NC-69-2	3	200	0.95	13.0	4.30	2.90	72	80	1.38			
NC-69-3	3	200	0.88	12.0	4.65	3.01	70.5	80	1.45			
NC-69-4	3	200	0.95	13.8	4.32	2.83	74	80	1.50			
NC-69-5	3	200	0.63	6.8	8.13	2.83	74	80	1.22			
NC-69-1	4	200	0.91	12.5	4.53	3.09	68	125	1.44			
NC-69-2	4	200	0.89	12.7	4.58	2.88	66	125	1.40			
NC-69-3	4	200	0.88	12.0	4.65	3.01	70.5	125	1.46			
NC-69-4	4	200	0.92	12.7	4.45	2.92	72	125	1.49			
NC-69-5	4	200	0.63	6.8	8.13	2.83	74	125	1.22			
NC-69-1	5	500	0.82	11.2	5.00	3.43	61	125	1.46			
NC-69-2	5	500	0.81	11.1	5.06	3.29	64	125	1.40			
NC-69-3	5	500	0.81	11.1	5.05	3.29	64	125	1.47			
NC-69-4	5	500	0.82	11.2	5.00	3.17	66	125	1.52			
NC-69-5	5	500	0.63	6.75	8.15	2.89	72.5	125	1.22			
NC-69-1	6	1000	0.69	9.45	5.95	4.08	51.5	125	1.49			
NC-69-2	6	1000	0.74	10.15	5.55	3.59	59.5	125	1.42			
NC-69-3	6	1000	0.75	10.30	5.45	3.55	60	125	1.48			
NC-69-4	6	1000	0.77	10.50	5.35	3.37	62.5	125	1.54			
NC-69-5	6	1000	0.53	5.70	9.65	3.40	62	125	1.23			
NC-69-1	7	1000	0.75	10.25	5.45	3.75	55.5	80	1.48			
NC-69-2	7	1000	0.88	12.05	4.65	3.03	69.0	80	1.40			
NC-69-3	7	1000	0.73	10.00	5.60	3.65	57.2	80	1.48			
NC-69-4	7	1000	0.85	11.65	4.82	3.05	68.5	80	1.53			
NC-69-5	7	1000	0.59	6.35	8.63	3.05	68.5	80	1.22			

* Versus an Hg/HgO Reference Electrode

(continued)

Table I. Performance Data of Various Cadmium Anodes (Continued)

Cell No.	Cycle No.	Rate-Charge and Discharge (mA)		Capacity (Ah)	Ah per inch cubed	Plate Weight Per Ah (g/Ah)	Utilization of Cadmium (g/Ah)	% of Theoretical Capacity	Temp. °F	Final Potential (..) on Charge* (V)
NC-69-1	8	500		0.81	11.10	5.08	3.47	60.0	80	1.50
NC-69-2	8	500		0.95	13.00	4.32	2.80	74.5	80	1.40
NC-69-3	8	500		0.80	10.95	5.13	3.32	63.0	80	1.49
NC-69-4	8	500		0.90	12.35	4.56	2.89	72.5	80	1.52
NC-69-5	8	500		0.55	5.90	9.30	3.28	63.5	80	1.22
NC-69-1	9	200		0.42	5.73	9.80	6.70	31.0	-40	1.55
NC-69-2	9	200		0.61	8.35	6.70	4.30	49.5	-40	1.40
NC-69-3	9	200		0.49	6.75	8.35	5.43	38.5	-40	1.56
NC-69-4	9	200		0.60	8.22	6.85	4.32	48.5	-40	1.46
NC-69-5	9	200		0.22	3.05	22.3	8.15	25.5	-40	1.40
NC-69-1	10	1000		0.35	4.80	11.65	8.05	26.0	-25	1.70
NC-69-2	10	1000		0.52	7.10	7.90	5.12	40.7	-25	1.63
NC-69-3	10	1000		0.38	5.20	10.75	7.00	30.0	-25	1.68
NC-69-4	10	1000		0.50	6.85	8.20	5.18	40.3	-25	1.63
NC-69-5	10	1000		0.15	1.61	34.0	12.00	17.5	-25	1.60
NC-69-1	11	500		0.47	6.42	8.72	6.00	35.0	-25	1.56
NC-69-2	11	500		0.64	8.75	6.40	4.15	50.5	-25	1.51
NC-69-3	11	500		0.41	5.62	10.00	6.50	32.2	-25	1.54
NC-69-4	11	500		0.60	8.22	6.85	4.32	48.5	-25	1.51
NC-69-5	11	500		0.25	2.69	19.00	7.20	29.0	-25	1.44
NC-69-1	12	200		0.59	8.10	6.95	4.70	44.5	-25	1.48
NC-69-2	12	200		0.74	10.15	5.52	3.60	58.0	-25	1.43
NC-69-3	12	200		0.59	8.12	6.95	4.50	46.5	-25	1.47
NC-69-4	12	200		0.70	9.55	5.85	3.70	56.5	-25	1.45
NC-69-5	12	200		0.31	3.33	16.50	5.80	36.0	-25	1.27

* Versus an Hg/HgO Reference Electrode

(continued)

Table I. Performance Data of Various Cadmium Anodes (Continued)

Cell No.	Cycle No.	Rate-Charge and discharge (mA)	Capacity (Ah)	Ah per inch cubed	Plate Weight Per Ah (g/Ah)	Utilization of Cadmium (g/Ah)	% of Theoretical Capacity	Temp. °F	Final Potential (-) on Charge* (V)
NC-70-1	1	200	.67	9.2	6.20	4.32	48.5	80	1.03
NC-70-2A	1	200	.75	10.3	5.50	3.65	57.5	80	1.01
NC-70-3	1	200	.83	11.4	5.00	3.42	61.2	80	1.06
NC-70-2B	1	200	.76	10.4	5.45	3.62	58.0	80	1.07
NC-70-1	2	200	.81	11.1	5.12	3.60	58.0	80	1.03
NC-70-2A	2	200	.95	13.1	4.36	2.90	72.2	80	1.01
NC-70-3	2	200	.98	13.4	4.23	2.88	72.5	80	1.05
NC-70-2B	2	200	.97	13.3	4.28	2.85	73.2	80	1.07

Cell No.	Type	Negative & Composition	Wgt of Cd(g)	Plate Wgt (g)	Positives	Volume (-)
NC-69-1	Sponge	95 CdO + 5 Ni	2.82	4.12	2xGE-SAFT	0.73 in ³
NC-69-2	"	90 CdO + 5 Ni + 5 Fe ₂ O ₃	2.66	4.08	"	0.73 in ³
NC-69-3	"	94 CdO + 5 Ni + 1 In	2.66	4.10	"	0.73 in ³
NC-69-4	"	89 CdO + 5 Ni + 5 Fe ₂ O ₃ + 1 In	2.60	4.11	"	0.73 in ³
NC-69-5	Sintered Nickel	Cd(-) 100% Cd from Conotore	1.80	5.12	"	0.93 in ³
NC-70-1	Sponge	95 CdO + 5 Ni	2.90	4.14	2xGE-SAFT	0.73 in ³
NC-70-2A	"	90 CdO + 5 Ni + 5 Fe ₂ O ₃	2.75	4.17	"	"
NC-70-3	"	92.5 CdO + 5 Ni + 2 TiO ₂	2.83	4.13	"	"
NC-70-2B	"	90 CdO + 5 Ni + 5 Fe ₂ O ₃	2.75	4.13	"	"

* Versus an Hg/HgO Reference Electrode

Table II. Performance of Nickel-Hydroxide Positives as Affected By The Cadmium Anodes

Cell No.	Cycle No.	Rate-Charge and Discharge (mA)		Capacity (Ah)	Ah per inch cubed	Plate Weight Per Ah (g/Ah)	Utilization of Cadmium (g/Ah)	% of Theoretical Capacity	Temp. °F	Final Potential (+) on Charge* (V)	
NC-70-4	1,7	200		0.91	7.35	7.30	3.35	103	80	0.60	
NC-70-5	1,7	200		0.88	7.58	7.55	3.46	100	80	0.60	
NC-70-6	1,7	200		0.72	6.65	6.55	3.32	104	80	0.60	
NC-70-4	2,8	200		0.96	7.25	6.90	3.18	108.5	80	0.61	
NC-70-5	2,8	200		0.92	6.95	7.20	3.32	104	80	0.61	
NC-70-6	2,8	200		0.69	7.20	6.82	3.20	107.5	80	0.60	
NC-70-4	3	500		0.89	6.75	7.50	3.43	101	80	0.66	
NC-70-5	3	500		0.88	6.68	7.55	3.47	99	80	0.61	
NC-70-6	3	500		0.64	6.70	7.35	3.45	100	80	0.63	
NC-70-4	4	500		0.88	6.68	7.55	3.46	100	80	0.70	
NC-70-5	4	500		0.80	6.05	8.35	3.81	90	80	0.62	
NC-70-6	4	500		0.68	7.10	6.92	3.24	106.5	80	0.70	
NC-70-4	5,6	500		0.75	5.70	8.90	4.06	85	3	0.74	
NC-70-5	5,6	500		0.61	4.62	10.90	5.00	69	3	0.63	
NC-70-6	5,6	500		0.585	6.10	8.05	3.75	92	3	0.70	
NC-70-4	9	1000		0.77	5.85	8.70	3.95	87.5	80	0.66	
NC-70-5	9	1000		0.62	4.70	10.8	4.92	70.0	80	0.62	
NC-70-6	9	1000		0.62	6.45	7.60	3.55	97.5	80	0.66	
NC-70-4	10	500		0.35	19.0	2.65	8.70	40.0	-40	0.99	
NC-70-5	10	500		0.17	39.3	1.29	17.80	17.5	-40	0.94	
NC-70-6	10	500		0.29	16.2	3.63	6.05	57.0	-40	1.01	

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Versus an Hg/HgO Reference Electrode

(continued)

Table II. Performance of Nickel-Hydroxide Positives As Affected By The Cadmium Anodes (Continued)

Cell No.	Cycle No.	Rate-Charge and Discharge		Capacity (Ah)	Ah per inch cubed	Plate Weight Per Ah (g/Ah)	Utilization of Cadmium (g/Ah)	% of Theoretical Capacity	Temp. °F	Final Potential	
		(mA)	(mA)							(+) on Charge	(V)
NC-70-4	11	500		0.88	6.68	7.55	3.46	100	125		0.53
NC-70-5	11	500		0.79	6.03	8.40	3.86	89	125		0.50
NC-70-6	11	500		0.63	6.55	7.45	3.50	99	125		0.54
NC-70-4	12	500		0.54	4.08	12.35	5.65	61	160		0.54
NC-70-5	12	500		0.47	3.36	14.20	6.50	53	160		0.48
NC-70-6	12	500		0.46	4.80	10.20	4.78	72	160		0.54
NC-70-4	13	500		0.88	6.68	7.55	3.46	100	80		0.69
NC-70-5	13	500		0.79	6.00	8.40	3.86	89	80		0.63
NC-70-6	13	500		0.62	6.45	7.60	3.55	97.5	80		0.68

Cell No.	Type Positive	Type Negatives	Wgt of (+) - g		Wgt of Ni(OH) ₂ - g	Wgt of Cd - g		Volume of (+)	
NC-70-4	Texas Instruments	Sponge: 95 CdO + 5 Ni	6.65	3.05	2x2.86	0.132 in ³			
NC-70-5	"	Sponge: 90 CdO + 5 Ni + 5 Fe ₂ O ₃	6.65	3.05	2x2.75	0.132 in ³			
NC-70-6	SAFT (G.E.)	Sponge: 95 CdO + 5 Ni	4.70	2.20	2x2.86	0.096 in ³			

* Versus an Hg/HgO Reference Electrode